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POWDERY MILDEW OF THE GRAPE AND ITS CONTROL IN CALIFORNIA

H. E. JACOB[1]

Powdery mildew, or Oidium as it is called in Europe, is the most serious fungous disease of the vine that is present in California. It has been found in every vineyard section of the state. In the cooler and more humid regions it does great damage every year to all vines not properly treated. In the very hot and dry desert regions it does little or no damage except in occasional years when the weather is favorable to its development. Throughout the principal vineyard regions, except possibly the Colorado Desert regions, it is always dangerous, and preventive measures should always be employed.

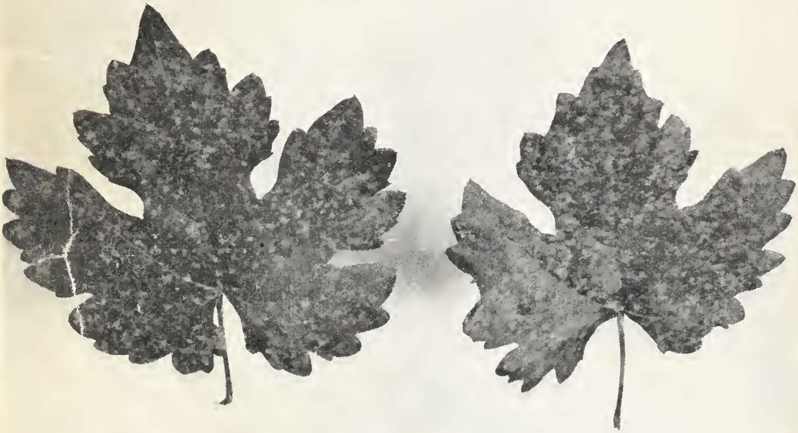

Fig. 1.—Mottled appearance of the leaves caused by patches of powdery mildew.

NATURE OF THE DISEASE

Symptoms.—Powdery mildew attacks all green parts of the vine. In the spring the young leaves that are attacked at first show whitish or greenish white patches on either the upper or lower surface, or both. A mottled appearance is thus produced (fig. 1). As the disease progresses these patches run together until a large portion of the leaf is covered with the grayish white powdery mildew. Sometimes the growth of the mildew is accompanied by distortion and discoloration of the affected leaves. The shoots of very badly affected vines may therefore have a wilted appearance (fig. 2). This is most noticeable early in the season. A badly affected vine emits a moldy odor.

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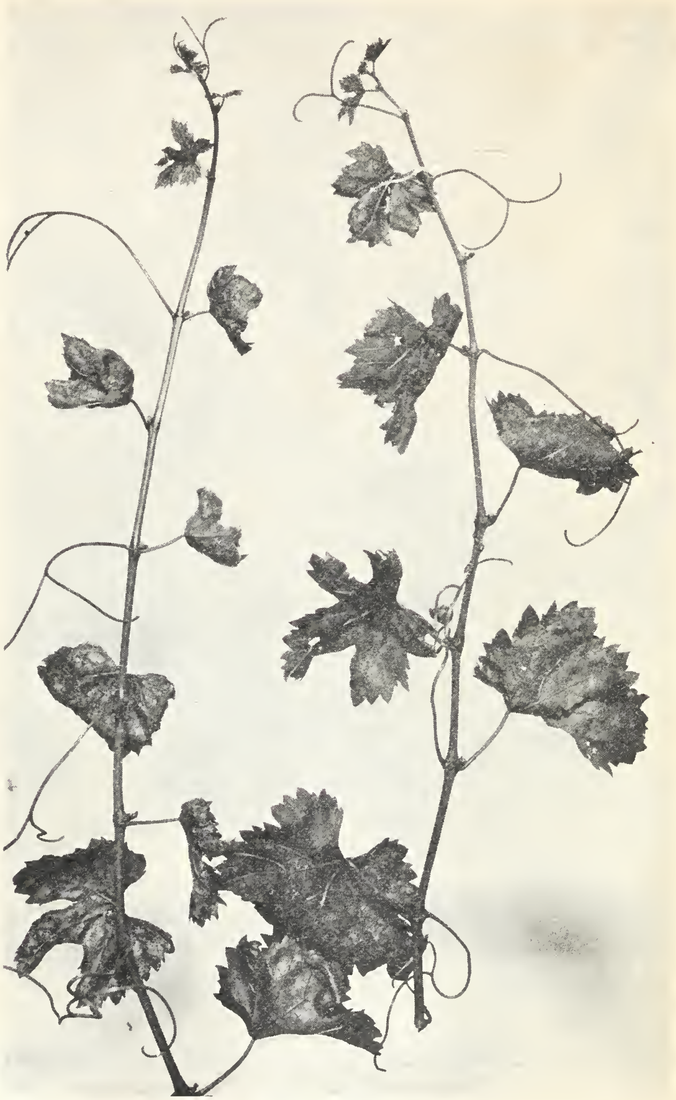

Fig. 2.—The wilted appearance of green shoots badly affected with powdery mildew.

On the green stems the earliest spots usually appear near the base and at first are not conspicuous. Later they take on a grayish tint and are then more easily seen. In severe cases the entire shoots may be covered. Late in the season the color of the affected areas darken, owing to injury to the outer cells of the bark (fig. 3). These areas, at first reddish brown and later black, are distinctly noticeable on the dormant canes.

If conditions at blossoming time are favorable to the growth of mildew, the blossoms may be attacked. Affected blossoms fail to set fruit.

The fruit may be attacked at any time until it begins to ripen. If the berries are attacked when very small, they fail to develop, and drop off. If the fruit reaches nearly full size before being affected it continues to develop, but irregularly. Sometimes this irregularity of development results in a cracking of the fruit, in which case the berries either dry up entirely and never ripen or are badly scarred.

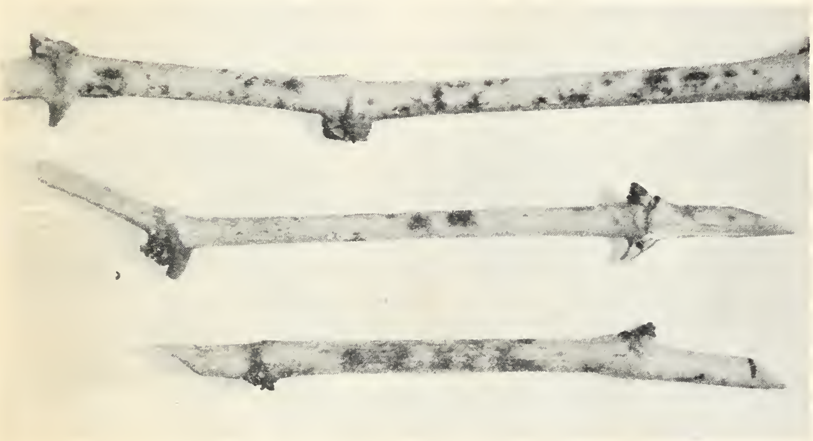

Fig. 3.—Blackened areas on dormant canes caused by powdery mildew.

Mildew on the stems of the bunches interferes with the nutrition of the berries, and poorly ripened fruit of low quality results.

Cause of the Disease.—This disease is caused by a fungus, *Uncinula necator* (Schw.) Burr., which is similar to the fungi which cause the mildews of roses, hops, beans, and apples. The mildews of these plants, however, are distinct species and cannot attack the vine. The fungous body (mycelium) grows on the *outside* of the vine and feeds by sending small organs (haustoria) into the tissues.

During the summer the fungus propagates itself by means of delicate, thin-walled summer spores (conidia). In the autumn, at least in the cooler parts of the state, winter spores (ascospores) are produced which are enclosed in thick-walled tough spore cases (perithecia) (fig. 4). These spores are able to withstand severe adverse weather conditions and also the corrosive action of strong sprays, and in the spring germinate and reproduce the fungus. In the hotter regions of the state, the ascospores are produced very sparsely or not at all. Under these conditions it seems probable that the fungous body itself is able to live through the winter on the canes or under the bud scales.

Powdery mildew is totally different from the disease called Downy Mildew or Peronospora, which occurs in Europe and the eastern part of the United States, but which has never been found in California.

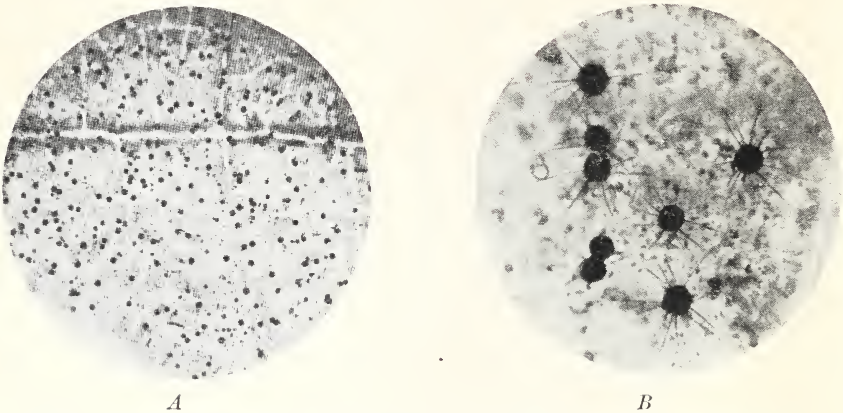

Fig. 4.—Photomicrographs of perithecia on surface of leaf. *A*, Magnified 8 times. *B*, Magnified 35 times.

Conditions Favoring the Disease.—There is considerable difference in the susceptibility of various varieties. All species of American vines—*Vitis labrusca*, *V. riparia*, *V. rupestris*, etc.—are much less severely attacked than *Vitis vinifera*. There is also a difference in the degree of susceptibility among the vinifera varieties. Among those most susceptible to the disease are Carignane, Black Corinth, and Rish Baba. Among the most resistant are Beclan, Alicante Bouschet, Mataro, and Petite Sirah (Duriff). All vinifera varieties, however, may be severely injured if weather conditions are favorable to the growth of the fungus and no control measures are used.

The powdery mildew fungus will grow at any temperature from 50° to 100° Fahrenheit. Below 50° F its growth is arrested. At 75° F its growth is rapid and reaches a maximum at 90°–95° F provided the air remains sufficiently moist. At about 100° F it ceases to grow and at a few degrees above this it is killed.

Though this fungus requires less moisture than most others causing diseases of the vine, it will not grow in an extremely dry atmosphere. In the drier regions of California it is much less troublesome than along the coast. Vines in moist places such as those bordering the banks of irrigation canals are often attacked when the rest of the vineyard is free. Rains or fogs in the spring or early summer are very favorable to the growth of powdery mildew, especially if the weather is warm.

FACTS ON WHICH CONTROL IS BASED

1. The fungus grows only on the outside surfaces of the vine.
2. It grows only on the green parts of the vine.
3. During the growing season of the vine, mildew spreads by delicate summer spores.
4. In the winter the fungus is chiefly in the form of very resistant resting spores, principally on and in the soil.
5. No practical method is known by which all the winter spores in a vineyard can be destroyed.
6. The germinating summer spores are easily and quickly killed by contact with sulfur or by its close proximity.
7. The mycelium or vegetative body of the fungus is more resistant than the summer spores to the effect of sulfur; hence it is destroyed more slowly by sulfur and a higher temperature is necessary.
8. Sulfur remains active and effective so long as it remains on the green parts of the vine.
9. It is possible, without injury to the vine, if the kind of sulfur and method of application are correct, to cover the green parts so completely with sulfur dust before the spores reach them that there is no possibility of infection.
10. The mycelium is killed quickly at any temperature by a suitable liquid fungicide.
11. It is not practicable to destroy completely *all* the mycelium by means of liquid spraying.
12. Mildew will not grow in hot, dry weather on leaves exposed to the sun.

PREVENTIVE TREATMENT

Treatment of any disease is either preventive or curative. A preventive measure is one to establish conditions that prevent the development of the disease. A curative measure is one used to kill the organisms, or to correct the conditions causing the disease, after the disease is established. It is very much easier to prevent this fungus from becoming established than to kill it after it has well started. Hence, careful attention should be given every season to the preventive treatment generally recognized as most effective, i.e., dusting with very finely divided dry sulfur.

Preventive treatment consists essentially in keeping all parts of the vine likely to be attacked covered with a very light coating of sulfur particles. (A heavy coating may cause 'sulfur burn' at temperatures over 100° F.) The particles of sulfur must be so close together that there is no place where a spore could fall and be far enough removed from a particle of sulfur to be uninjured. During the spring and early summer in the principal grape regions of California, all green parts of the vine must be kept covered with a coating of sulfur. In the interior valleys later in the season the dryness of the air and the high temperature in the outer parts of the vine are unfavorable to the growth of the fungus but the interior of the vine which is shaded and hence cooler and more moist will still be susceptible. With late-maturing varieties especially it is necessary to keep the interior of the vine covered with sulfur to avoid damage.

The sulfur must be present when the winter spores germinate and give rise to the summer spores. Germination of the winter spores probably begins soon after the vines start growth. An application of sulfur before the start of growth of mildew protects the leaves covered at that time, but does not protect the leaves that grow after this application. Usually three applications are necessary before blooming.

In the coast regions, weather conditions remain favorable to the growth of mildew during most of the growing season. In these regions it is therefore necessary to keep all the green parts of the vine covered with a coating of sulfur throughout the season. In the interior valleys where the weather usually becomes hot and dry after blooming it is necessary only to maintain the protective covering of sulfur on the green parts of the interior of the vines.

Season of Application.—Since the main object of sulfur treatment is to *prevent* the growth of mildew, it is essential that the sulfur be on the vines before mildew is likely to start growth in the spring, and also that all green surfaces be covered with sulfur particles close enough together so that the mildew has no place to start. To accomplish this in most sections of the state, it is necessary to make the first application when the green shoots are 6 or 8 inches long. It is unlikely that the mildew ever starts growth before this stage is reached. Furthermore with the shoots no longer than 8 inches, the vine is sufficiently open so that every leaf and stem can be perfectly covered. The surfaces covered by this first application are protected as long as the sulfur remains on them, probably most of the season. However, the vines are growing rapidly at this season of the year, and new leaves and stems are being formed which obviously received no sulfur at the first application. A second application should be given, therefore, when the green shoots average 15 to 18 inches in

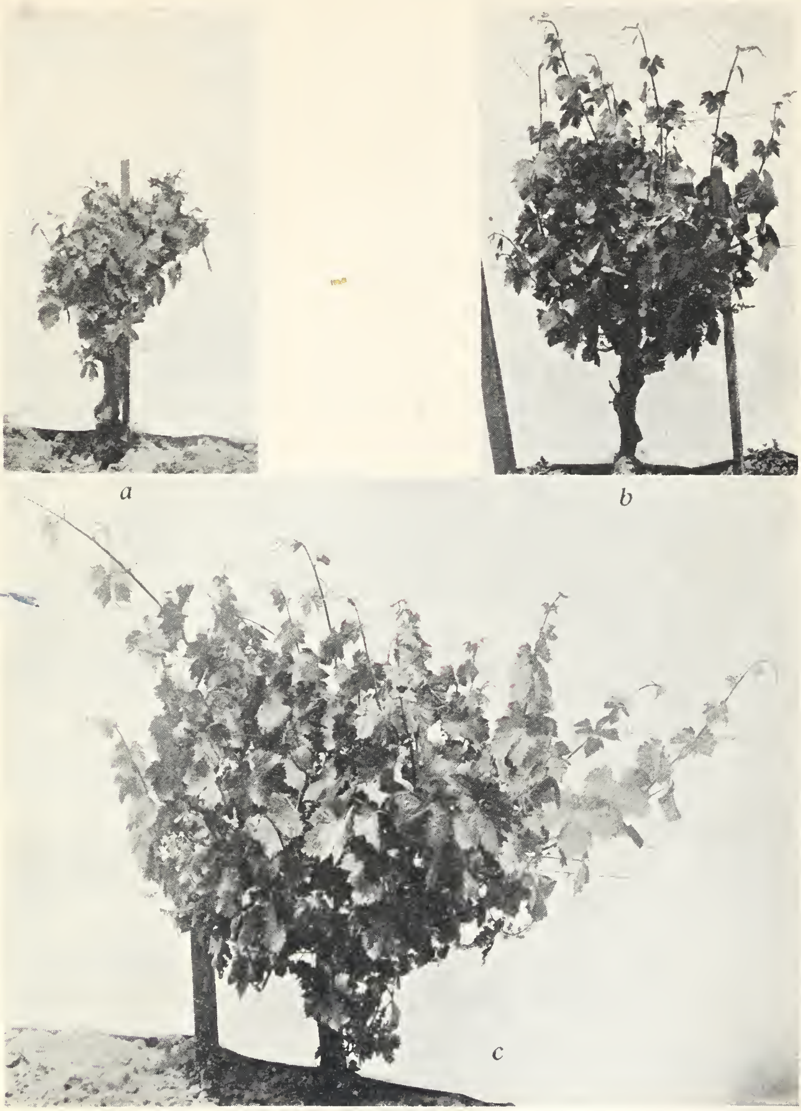

Fig. 5.—Stages at which vines should be sulfured to prevent mildew. *A*, Proper stage for the first application. *B*, Proper stage for the second application. *C*, Proper stage for the third application.

length, and a third when they are 2 to 3 feet long. Figure 5 shows vines in the proper stages for each of these three applications. The third application will usually come near blooming time. Sulfuring while the vines are in bloom does no damage.

These three early applications if properly done will completely protect the vines during the spring and early summer. In the interior valleys, the hot, dry weather after blooming usually prevents the growth of mildew on the exposed parts of the vine, and on the shaded parts the sulfur present is sufficient to prevent the growth of mildew until the fruit of the early varieties has ripened. Some new growth, however, is always taking place in the interior of the vine during the summer and this new growth, because it has no sulfur on it, offers opportunity for the mildew to start. With late-maturing grapes, therefore, it is not always safe, even in the interior valleys, to rest after the three applications have been made; it is advisable to make a fourth application when the berries are one-fourth to one-third grown. With this late application the interior of the vine and especially the bunches should be well sulfured.

In the coast regions where weather conditions are more favorable to the growth of mildew, the entire vine must be protected with sulfur throughout most of the season. The three applications before blooming will adequately protect the vines until the fruit is set, but a fourth application should be made soon after blooming and usually a fifth when the berries are about half grown. In these regions the entire vine should be thoroughly covered at each application.

Amount of Sulfur Necessary.—The number of sulfur particles necessary to protect the entire surface of a large vine is very great, since these sulfur particles must be only a very small distance apart. However, with our very finely divided modern dusting sulfurs, a single pound contains a vast number of individual particles. If it could be evenly distributed without waste, one pound of good sulfur is ample to cover an acre of large vines. It is of course impossible to avoid some waste and the quantity of sulfur actually used in careful work with modern machinery varies from five to twenty pounds per acre for each application. Five pounds is about the minimum with which one can cover an acre of average vineyard without undue waste of labor, and the use of more than twenty pounds per acre, even on the largest vines, is an unnecessary waste of sulfur caused either by the use of poor machinery or improper use of good machinery. The first two applications will usually require from 5 to 10 pounds per acre for each application and later applications from 8 to 15 pounds.

Manner of Application.—The sulfur should be applied so that all green surfaces are evenly coated with sulfur but nowhere should there be enough sulfur to discolor the foliage. This can be most easily accomplished by forming a cloud of sulfur dust some distance away from the vine and allowing this cloud to drift over and through the vine, completely enveloping it as it passes. The movement of the cloud should be carefully watched to be sure that all parts of the vine are at some time enveloped. As this cloud passes over the vine, sufficient sulfur will settle on the surfaces of the vine to completely protect it as long as the sulfur remains there. By no other known method can a vine be more thoroughly covered without a dangerous accumulation of sulfur on some parts.

Danger of Too Much Sulfur.—If during very hot weather an excess of sulfur is present on the tender green tissues of the leaves or fruit, injury, so-called 'sulfur burning,' will result. With a temperature above 100° F, exposed green tissues which have enough sulfur on them so that it can be readily seen because of its yellow color, are liable to be severely injured. Occasionally the injury done to both leaves and fruit by the action of excessive quantities of sulfur in very hot weather is as great as that resulting from a severe attack of mildew. Sulfur injury seldom, if ever, occurs until the temperature goes above 100° F. The nature of the injury is a chemical burn which kills the tissues and causes them to turn dark or nearly black.

Proper Time and Weather for Sulfuring.—The time of day at which the sulfur is applied is of little or no consequence, provided the weather is suitable. It may be applied when the leaves are dry or only slightly moist with dew, but should not be applied when the leaves are very wet, because the sulfur then falls on the film of water covering the leaf, and as the water dries, the sulfur collects in patches, leaving parts of the leaf unprotected. Also wet leaves stick together and this prevents covering the adhering surfaces. It is impossible to do the work properly in a high wind, but a gentle breeze is an aid in carrying the cloud of sulfur over and through the vines. Sulfuring in very hot weather (over 100° F) should be avoided on account of the danger of burning the grapes and foliage. Sulfuring in cool weather is not objectionable. The sulfur is not very active at low temperatures, but if applied during cool weather it will be present and become active when the temperature rises.

In irrigated vineyards it is a good practice to time the applications of water so that the sulfuring immediately precedes the irrigation.

The moist conditions immediately following an irrigation favor the growth of mildew, and a complete protective covering of sulfur is desirable during this period. If the sulfuring is delayed until after irrigation, it cannot be done for a day or two because of the wet condition of the ground and in the meantime the fungus may become established.

If a heavy rain immediately follows an application of sulfur the application should be repeated. However, the sulfuring should not be delayed in anticipation of rain, for the small amount of sulfur that is not washed off is the finest and most effective and is of very great value during the cool moist weather following the rain. A light rain or heavy dew will not wash off enough sulfur to make it necessary to repeat the application.

Suckering of the Vines in Relation to Mildew Control.—Suckers and watersprouts are usually the most rapidly growing shoots on a vine. They quickly form a large amount of unprotected green leaves and stems after an application of sulfur. Also they grow near or through the centers of the vines where the foliage is densest and most difficult to dust properly. Hence they are particularly susceptible to attack by mildew. They are best removed before the vineyard is dusted, for (1) their early removal eliminates the possibility of mildew starting on them; (2) their removal makes the foliage less dense and hence the remainder of the vine can be more thoroughly dusted; (3) it is unpleasant to work in the vines soon after dusting with sulfur.

Dusting Machines.—Any means that will produce a thin cloud of sulfur which will envelope a vine and not deposit conspicuous masses of sulfur on the foliage can be used to dust vines. For economical and efficient work, however, certain types of knapsack or power dusting machines are advisable.

Knapsack machines.—These machines, which are hand operated, are of two types: (1) producing the current of air by means of a bellows, and (2) producing the current of air by means of a rotary blower. Both types are provided with straps for carrying the machine and either type can be made to do good work. Because of their easier working properties and better adaptability for intermittent work, e.g., dusting individual vines, the bellows type is generally preferred for vineyard work. Figure 6 shows such a machine in operation. This type of machine will waste the least sulfur of any of the common types and can be made to do perfect work with a low labor cost. One man equipped with a good bellows-type knapsack duster can treat one or two acres an hour, using from 5 to 10 pounds of sulfur an acre according to the size and number of the vines.

Power machines.—All of these make use of rotary blowers. They are of various types and quality. Some have the blower driver by power transmitted from the wheels on which the machine is carried, the power being furnished by a team of horses pulling the outfit. Most of these machines are supplied with equipment for covering two rows at a time. On small low vines and in quiet weather they appear to do fairly satisfactory work when used in this manner. With large vines, however, it is practically impossible to satisfactorily cover two rows at a time with this type of machine. If the entire output of the machine is delivered through one nozzle and that nozzle carefully manipulated by the operator of the machine, good work can be done even on fairly large vines, but only on one row at a time.

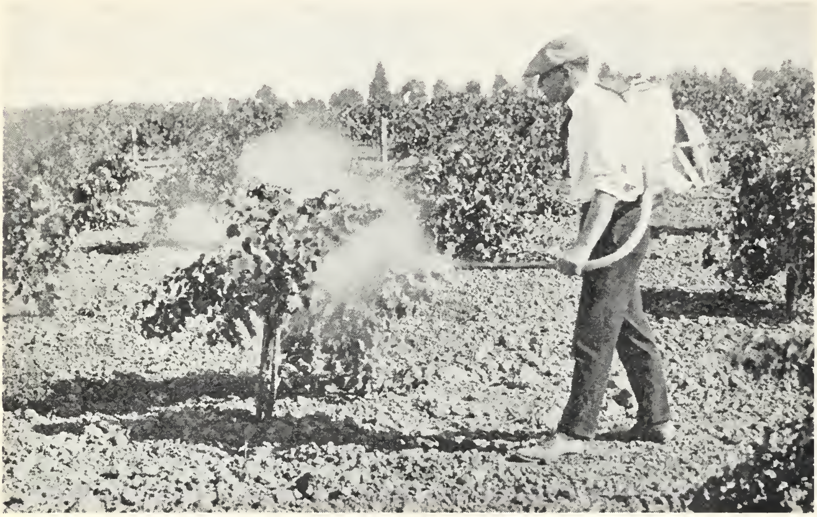

Fig. 6.—Knapsack-type dusting machine in operation. A cloud of sulfur dust is formed and allowed to drift over the vine.

Engine-driven power machines have been developed in recent years which will thoroughly cover, simultaneously, two rows of large vines planted not more than 15 feet apart, as rapidly as the machine can be driven across the vineyard and without the use of extravagant quantities of sulfur. These large machines are driven by means of gasoline engines usually of 4 or more horsepower, and produce a current of air strong enough to overcome the effects of slight adverse winds. The first cost of such a machine is considerable, but on a large vineyard where difficulty is usually experienced in obtaining enough careful men to do the dusting with knapsack machines, their efficiency cannot be questioned. They will cover from 30 to 50 acres a day and use from 8 to 15 pounds of sulfur per acre at each application, provided of course that they are properly adjusted, operated by a capable man and drawn by a fast-walking team or a tractor. Figure 7 shows such a machine.

Kinds of Sulfur.—The essential qualities of a good dusting sulfur are (1) fineness, (2) ease of working, and (3) purity. The finer the sulfur, i.e., the smaller the individual particles, the more effective it is in controlling mildew. This is true at least within the limits of practical, present-day manufacturing methods. The very finely divided sulfur has greater covering capacity and adheres better to the plant surfaces than does a coarser dust. The sulfur must not only be very finely divided but the particles must separate readily from one another. It is of little value to produce a very finely divided sulfur if it 'cakes' later and is delivered from the dusting machine in the form of lumps. The sulfur must be delivered from the dusting machine in a very finely divided state so that it stays suspended in the air until the cloud passes over and envelopes the vine or parts of the vine. A very good dusting sulfur will 'float' in the air for several minutes after delivery from the machine. A coarse sulfur settles to the ground very quickly.

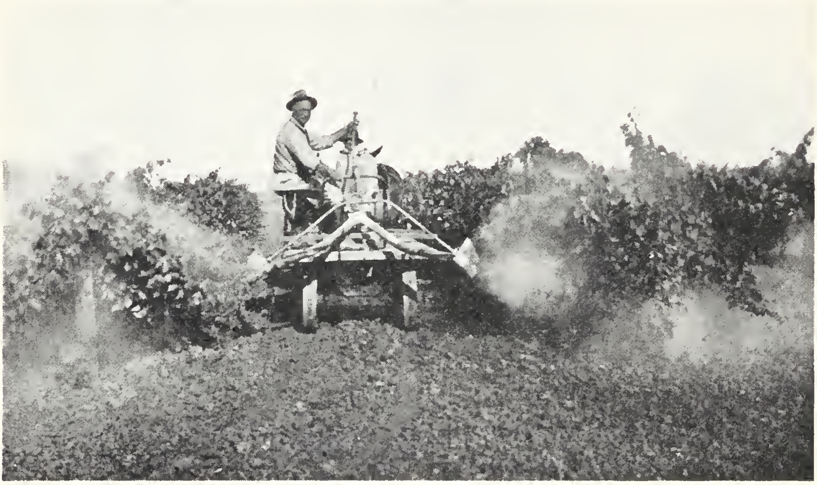

Fig. 7.—An engine-driven power dusting machine.

The absolute purity of the sulfur is of little importance, provided there is no large adulteration with inert and useless material. Most of the dusting sulfur sold in California for vineyard dusting is practically pure.

The method of manufacture is of little or no importance so long as the sulfur produced is nearly pure, very finely divided and distributes freely without lumps. The principal methods used in America for pulverizing the sulfur are subliming and grinding. The former method produces the so-called sublimed sulfur or 'flowers of sulfur' which when very finely divided is intensely yellow and rather bulky. The grinding process produces the so-called ground sulfur, which is whitish yellow and less bulky than the sublimed sulfur. So far as is known there are no differences between these sulfurs in their effectiveness in controlling mildew.

A very simple and yet fairly reliable test which anyone can make to determine the fineness and ease of working of a dusting sulfur is that of rubbing a very small quantity between the fingers or in the palm of the hand. A good sulfur feels like talcum powder—without grit. Also, the lumps of sulfur, if any are present, should pulverize perfectly with very little pressure. A coarse sulfur feels like fine sand. If a given sample is free from lumps and feels perfectly smooth when rubbed in the hand and is nearly pure, it can be considered as a perfectly satisfactory dusting sulfur. If it feels very gritty, however, or has hard lumps in it, it is probably of an inferior grade and should not be used if a finer sulfur can be obtained.

CURATIVE METHODS

Liquid Spraying.—It occasionally happens, owing presumably to inadequate preventive treatments, that a severe attack of mildew does occur in even a well-cared-for vineyard. When once well started in weather favorable to its growth, the action of sulfur alone is too slow to check mildew before considerable damage is done. Under these conditions a liquid spray is advisable. For this purpose a potassium permanganate spray is recommended because it will kill all of the fungus with which it comes in contact very quickly and will not spot the fruit badly. Bordeaux mixture and lime-sulfur will kill the fungus but leave unsightly stains on the fruit.

The potassium permanganate spray consists of 1 pound of potassium permanganate dissolved in 75 gallons of water. To cause the spray to spread better and wet the foliage more thoroughly, about

1 pound of sodium silicate (water glass) and ⅓ of a pound of baking soda should be added to each 75 gallons. The materials should be thoroughly dissolved in the water and thoroughly mixed before applying to the vines. In applying the spray an effort should be made to throughly wet the interior of the vine where the mildew is most abundant.

This liquid spray kills only those parts of the fungus that it actually wets and has little or no effect in preventing further growth of that which is not killed. It is very difficult to thoroughly wet the entire surface of a large dense vine. To prevent further attack therefore, the vines should be carefully and thoroughly sulfured as soon as the vines are dry after spraying. This sulfuring should not be delayed more than a day or two after the application of the spray. The liquid potassium permanganate spray followed by dusting with dry sulfur is usually sufficient to check even a very severe attack of mildew.

The cost of this treatment is considerably more than that of one or two extra sulfurings, and it should not be relied upon to take the place of careful dusting with dry sulfur early in the season. In the case of vine mildew, truly ''an ounce of prevention is worth a pound of cure.''

Winter Spraying is Ineffective.—As the fungus passes the winter, when it has no green leaves to grow on, chiefly in the form of resting spores on the canes and in the soil and in the form of inactive mycelium on canes and under the bud scales, it has been suggested that a winter treatment which would destroy these hibernating forms would be an effective method of control, or at least that it would simplify the summer treatment. However, in experiment[2] and practice, winter spraying has not proved effective in controlling mildew. If it be assumed that the fungus passes the winter chiefly in the form of the winter spores, which seems to be the case, at least in the cooler sections of the state, the failure of winter spraying to control mildew is not surprising, for the majority of the winter spores are on or in the soil where the spray would not reach them; furthermore, the spore cases which enclose these winter spores are very tough and resistant and protect the spores within from the corrosive action of the spray.

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[2] The results of certain experiments with liquid sprays and dusting with dry sulfur are given in: Bioletti, Frederic T., and F. C. H. Flossfeder, Oidium or powdery mildew of the vine. California Exp. Sta. Cir. 144:1–12. 1915. (Out of print.)

SUMMARY

1. Powdery mildew is the most serious fungous disease of the vine that is present in California, and in most vineyard regions of the state is dangerous every year.

2. It attacks all green parts of the vine including stems, leaves, and berries.

3. The disease is caused by a fungus that grows on the *outside* surfaces of the vine, and obtains its nourishment by means of minute organs (haustoria) which penetrate the outer tissues of the vine.

4. During the summer the fungus spreads principally by means of delicate summer spores. It passes the winter in a resting stage, chiefly winter spores which are enclosed in very tough spore cases.

5. The fungus grows best during warm, moderately moist weather. It grows rapidly at temperatures between 75° and 95° F and does not grow below 50° nor above 100° F.

6. It is much easier to prevent the fungus from becoming established than to kill it after it has well started.

7. The fungous body (mycelium) is quickly killed by a suitable liquid fungicide when brought in contact with it, but it is difficult or impossible to kill all of the fungus by this means.

8. The germination of the spores and the growth of the fungus is prevented by the close proximity of sulfur, and it is possible to cover the green parts of a vine so completely with sulfur dust before the spores reach them that infection is impossible.

9. It is usually necessary to repeat the application of sulfur several times to cover new parts that develop after the earlier applications. All green areas must be protected with sulfur so long as the weather conditions favor the development of mildew.

10. Usually from 3 to 5 applications are recomended. First when the new shoots are 6 or 8 inches long; second when they are 15 to 18 inches long; third when they are 2 to 3 feet long, which will be at or near blooming time; fourth, when the berries are well set; and fifth, when the berries are about half grown.

11. In the interior valleys, the first three sulfurings are usually sufficient for early-maturing varieties. For late-maturing varieties, a fourth application is advisable. In the coast regious the full schedule of five applications is usually necessary every year.

12. For vines of average size, and with good machinery, from 5 to 15 pounds of sulfur per acre per application are usually used. Very large vines may occasionally require slightly more.

13. Too much sulfur on the vines will cause 'burning' of the vines in hot weather. This damage may occur at any time the temperature goes above 100° F if enough sulfur is present.

14. High winds, wet vines, and very hot weather should be avoided in sulfuring vines, otherwise weather conditions and time of day need have no influence on the time of application.

15. It is better to sulfur the vines just before than just after irrigation.

16. When suckering is needed it should be done before dusting with sulfur.

17. Knapsack dusting machines of the bellows type are most commonly used for vineyard dusting and are to be recommended for small vineyards.

18. Modern engine-driven power dusting machines are capable of doing excellent work and can be recommended for large vineyards where the quantity of work to be done justifies the high initial cost.

19. To be most effective, dusting sulfur should be extremely fine, easy to work, and free from adulterants.

20. A liquid spray of potassium permanganate (1 pound to 75 gallons of water with sodium silicate and baking soda spreader) will kill all of the fungus with which it comes in contact and will not injure the vines nor badly stain the fruit. This spray should be followed with a dusting of sulfur soon after the vines are dry.

21. Winter spraying is ineffective in controlling mildew and is not recommended for this purpose.

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